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13. ABSTRACT (Maximum 200 words) Specific concurrent engineering practices vary among organizations. There are, however, various management practices that appear to work well for most organizations. This paper presents the reader with specific, useful examples from several defense contractors illustrating how multifunctional concurrent engineering teams are being organized and managed and how concurrent engineering team meetings are conducted and supported. The types of computer support that could be used to enhance the efficiency and effectiveness of concurrent engineering team meetings are identified. The general findings are that there exists a direct relationship between total quality management (TQM) and concurrent engineering, and that many applications of computer-aided group problem solving are possible and practical today for the concurrent engineering team meetings. Areas identified for additional research are the documentation of the decision process and rationale during the product and process definition, the capturing of lessons learned during the implementation of concurrent engineering, and the performance evaluation and training of team members.				
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CONCURRENT ENGINEERING TEAMS

Volume I: Main Text

David A. Dierolf
Karen J. Richter

November 1990



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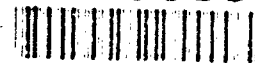
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PREFACE

This paper is the result of work performed by the Institute for Defense Analyses (IDA) under contract number MDA 903 89 C 0003, task order T-D6-554, "Measurement Issues in Unified Life Cycle Engineering." This work was performed for the Air Force Human Resources Laboratory, Logistics and Human Factors Division, and the Under Secretary of Defense for Acquisition (USD(A)).

This paper specifically addresses the management and organizational issues surrounding concurrent engineering teams and their meetings and identifies the types of computer support that would be beneficial to the group problem solving activities of the concurrent engineering teams.

This paper was reviewed by Dr. Paul Richanbach, Strategy, Forces and Resources Division (SFRD), Dr. Dick Cheslaw, Cost Analysis Research Division (CARD), and Dr. Jim Pennell, Computer and Software Engineering Division (CSED), Institute for Defense Analyses (IDA).



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The authors also wish to thank Leta Horine for her diligence and perseverance in preparing this paper, including the comprehensive annotated bibliographies of Volume II.

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GLOSSARY

AFHRL	Air Force Human Resources Laboratory
AIRMICS	U.S. Army Institute for Research in Management Information
ASD	Aeronautical Systems Division
ATF	Advanced Tactical Fighter
CAD	Computer-Aided Design
CALCE	Computer-Aided Life Cycle Engineering
CALS	Computer-Aided Acquisition and Logistics Support
CDC	Composite Development Center
CIM	Computer Integrated Manufacturing
DFA	Design for Assembly
DoD	Department of Defense
DTG	Decision Techtronics Group
GDLS	General Dynamics Land Systems
GDSS	Group Decision Support Systems
IDA	Institute for Defense Analyses
IM	Interactive Management
IPT	Integrated Product Teams
LASC	Lockheed Aeronautical Systems Company
LCC	Life Cycle Cost
LHX	Light Helicopter Experimental
MCC	Microelectronics and Computer Technology Corporation
MDMSC	McDonnell Douglas Missile Systems Company
MOA	Memorandum of Agreement
NAD	Northrop Aircraft Division
NCR	National Cash Register (Corporation)
QFD	Quality Function Deployment
SIE	Systems Integration Engineering
3D	Three-dimensional
TQM	Total Quality Management
ULCE	Unified Life Cycle Engineering
USD(A)	Under Secretary of Defense for Acquisition
WBS	Work Breakdown Structure

EXECUTIVE SUMMARY

Concurrent engineering is a systematic approach to the integrated, parallel development of products and their related manufacturing and support processes to increase customer satisfaction. TQM is a management philosophy that involves participation by everyone in an organization to achieve customer satisfaction through continuous improvement. TQM focuses on error prevention and the elimination of waste and stresses building quality into all of the processes of an organization, whether the organization performs one or a combination of the functions of defining, building, or servicing products for its customers. Not only is concurrent engineering consistent with the Total Quality Management (TQM) philosophy and way of doing business, but in the authors' view, concurrent engineering is TQM applied to the engineering, or product development, process.

A universal element in the practice of concurrent engineering and TQM is the problem solving team that participates in regular, formal meetings. The multifunctional concurrent engineering team engages in the fundamental problem solving process of product and process definition. Although higher overall productivity has been shown to result from multifunction team problem solving in product and process definition (Winner, *et al.* 1988), initial productivity loss is often associated group problem solving. This paper presents the organizational structures and management practices used by companies in their implementation of concurrent engineering and focuses on the organization, management practices, and support used to minimize the inefficiency often associated with meetings. The authors then present technology resources that could be used to support the human interaction in the team meetings. These technology resources are intended for organizations practicing concurrent engineering to derive the benefits of group work while minimizing the productivity loss often associated with group work.

A. APPROACH

To provide the reader with useful examples showing how concurrent engineering teams are being organized and managed and how the concurrent engineering team meetings are conducted and supported, the research team reviewed the literature, attended various conferences, and visited several defense contractors. The literature reviewed for this study

is compiled in an annotated bibliography as Volume II of this paper. The companies visited during this study were McDonnell Douglas Helicopter Company in Mesa, Arizona; Northrop Aircraft Division in Hawthorne, California; Lockheed Aeronautical Systems Company (LASC) in Burbank California; General Dynamics Land Systems (GDLS) in Sterling Heights, Michigan; and McDonnell Douglas Aircraft Company (McAir) and McDonnell Douglas Missile Systems Company (MDMSC) in St. Louis, Missouri. Many of the statements made in this paper derive from specific lessons learned by concurrent engineering teams at the different companies. Whenever possible, the authors attribute the information to specific organizations.

B. FINDINGS

In the summer of 1990, the French Ministry of Defense sent a delegation to this country to visit various defense contractors to obtain information about how concurrent engineering is being implemented. One of the members of the delegation remarked that each company had their own vision of what concurrent engineering is and how to implement it. He seemed surprised at this--that there wasn't one standard way that all organizations followed. A basic finding of this study is that there is no one way to *do* concurrent engineering, or even a best way. Concurrent engineering reflects a philosophy and a way of doing business that is consistent with Total Quality Management (TQM). Once an organization accepts the philosophy behind concurrent engineering, how it is actually *done* is very dependent on the history of the organization and its existing culture, tools, and procedures. In fact, during the authors' site visits to the various companies involved in this study, it became evident that the concurrent engineering program in a company depends largely on the advocate of concurrent engineering in the company--the characteristics of the program seem to follow the character of the concurrent engineering manager.

1. Organization and Management of Concurrent Engineering Teams

The success of each concurrent engineering project clearly depends on the ability of the team members to work together; thus, total team satisfaction with the process and the resulting product and process definition is pivotal. Achieving consensus among members of a concurrent engineering team means arriving at a product and process definition that every member accepts. The multifunctional nature of the teams complicates the group dynamics because of the language barriers, perceptions of unequal status, and general cultural barriers to teamwork. Once consensus is achieved among the team members, it is

essential that buy-in is achieved from the team sponsor and upper managers. Various organizational structures and team management practices exist to overcome these difficulties and accomplish the concurrent engineering team approach to product and process definition. The key element of all of the methods used, however, is maintaining open communication during the process. All companies stressed the importance of clear, concise statements of the team's mission, goals, resources, and constraints; accurate but concise recording of the team activities distributed to all relevant people in the organization; and ongoing briefings of team progress to other stakeholders. Collocation of the team members allows them to communicate on a daily basis and to gain an understanding of each other's perspective.

2. Concurrent Engineering Team Meetings

Discipline in the meetings is an important element contributing to the success of concurrent engineering team meetings and, thus, of the team itself. Companies emphasize that meetings cannot be held just to have meetings. Meeting activities are generally strictly limited to the agenda items, and all of these activities have a deliverable focus. What is said during the meetings is strictly recorded, and this meeting documentation should exist for the management and program reviews as well as the regular meetings. Additional support people generally become part of the team--the facilitator and the recorder. The facilitator has expertise in group dynamics and group problem solving methods and concentrates on the process of the team meeting rather than the technical content. The recorder at a meeting is the scribe who records the minutes of the meeting. The recorder must be careful not to alter the meaning of any team member's contribution when documenting the meeting. The recorder, like the facilitator, must be a neutral, non-evaluating servant of the team during the meeting. In addition, having a single designated room for all of the team meetings where the complete schedule and process diagrams are displayed and the action items are posted, helps focus the team members.

3. Computer Support for Concurrent Engineering Team Meetings

Many of the significant improvements attributed to concurrent engineering come from changes in the management of the product and process definition activities rather than advances in computer technology. If the philosophy and principles guiding the company's behavior are wrong, no amount of effort or additional resources, including automation, will keep the company competitive. However, computers will continue to have a significant role in all types of work. Improving existing, and finding new, applications of computer

technology will certainly become part of most organizations' continuous improvement activities. A growing number of researchers are exploring ways to combine communication, computer, decision, and group process technologies and methodologies to support meetings. Proposed methods of introducing computer support for meetings can be as simple as computer-controlled audiovisuals or the use of software designed for a single user (e.g., word processing, spreadsheets, outline processors) or as complex as the use of elaborate meeting rooms that provide a computer for every participant. In the near term concurrent engineering meeting support will most likely be through software designed for single-users being employed in group settings. The more elaborate, multiple computer support systems warrant further research, especially in recognition of their demonstrated success in the face-to-face group support in business applications and their potential to support physically separated teams. A key requirement for any computer system that supports concurrent engineering meetings is that it integrates efficiently with the other computer systems that support the concurrent engineering team (e.g., Computer-Aided Design, engineering data management).

I. INTRODUCTION

Concurrent engineering is a systematic approach to the integrated, parallel development of products and their related manufacturing and support processes to increase customer satisfaction. Not only is it consistent with the Total Quality Management (TQM) philosophy and way of doing business, but in the authors' view, concurrent engineering is TQM applied to the engineering, or product development, process.

A universal element in the practice of concurrent engineering and TQM is the multifunctional problem solving team. The multifunctional concurrent engineering team engages in the fundamental problem solving process of product and process definition. In general, the benefits of doing team work are as follows (Warfield, 1986):

- The team has a greater sum total of knowledge and information to apply to the problem solution.
- The diverse experiences and viewpoints of multiple participants yield a greater number of approaches to the problem solution.
- Team members understand and support more strongly a solution that they help to determine.
- Participants obtain a common, clear understanding of requirements, configuration, and data.

Although higher overall productivity has been shown to result from multifunction team problem solving in product and process definition (Winner, *et al.* 1988), initial productivity loss is often associated group problem solving. The social science community has identified several reasons why group problem solving can reduce productivity (Kraemer and King, 1986; Warfield, 1986; Nadler, 1981; Delbecq, Van de Ven, and Gustafson, 1975). Essentially, they are--

- Information loss due to group pressure leading to conformity of thought
 - Discussions are dominated by certain individuals.
 - Low-status members defer to high-status members--dominant individuals exercise undue sway, provide pressure toward compromise.

- Information distortion
 - Miscommunication among members is common.
 - Goal of solution to problem may be replaced with secondary goal of winning an argument.
- Ineffectual decision making because insufficient time is spent in problem exploration and generation of alternatives.
- Inefficient individual activity and progress due to incremental changes and poor communication, causing confusion.

Since design and manufacturing are heavily dependent upon computer support, much of the literature and many of the activities surrounding concurrent engineering efforts focus on the computer. However, in defining concurrent engineering, Nevins and Whitney (1989) state--

By integration we do not mean to imply any particular implementation or technology. The correct role of computers and "computer integration" is unclear at this point. The same may be said of robots, expert systems, and other new developments. The importance of human relations and interactions, and organizational and institutional arrangements, is only dimly perceived, although many observers are convinced that these issues far outweigh technology in forming an effectively integrated approach. Yet the demands of complex products and processes strongly indicate that technology will be needed. The issue is to design, choose technology, and operate human-machine systems wisely.

This paper presents many of the human integration issues associated with concurrent engineering, including how concurrent engineering teams are organized and managed, and how the concurrent engineering team meetings are conducted and supported. Recognizing that advanced computer tools are the enablers for concurrent engineering (McAfee 1990) and not the foundation of it, this paper also presents technology resources that could be used to support the human interaction in the team meetings. These technology resources are intended for organizations practicing concurrent engineering to derive the benefits of group work while minimizing the productivity loss associated with group work.

A. BACKGROUND

Unified Life Cycle Engineering (ULCE), an Air Force Project Forecast II Research and Development program, began in 1987 with the goal of developing an engineering environment in which the quality of a product is improved by integrating the early consideration of producibility and supportability with performance, cost, and schedule. This envisioned environment would make use of advanced computing technologies.

A research team at the Institute for Defense Analyses (IDA), including the authors of this paper, has participated in ULCE research for the Air Force Human Resources Laboratory (AFHRL), Logistics and Human Factors Division, since the inception of the program. In investigating the various techniques that industry uses to evaluate producibility and supportability during the early phases of the product development process, the IDA research team identified a trend toward concurrent engineering. In concurrent engineering, integration is accomplished through the use of a multifunctional product development team, and customer satisfaction is assured through a continual focus on the customer's needs.

The IDA team then initiated research into concurrent engineering and the use of computers to support group problem solving to determine the implications to the ULCE program of the new approaches to product development and the use of computer support for multifunctional team problem solving. The researchers presented the results of this work in *Computer-Aided Group Problem Solving for Unified Life Cycle Engineering (ULCE)* (Dierolf and Richter, 1989). The authors recommended that the ULCE program broaden its focus to include research in computer-aided group problem solving to enhance the effectiveness of product and process definition teams. To support the recommendation, the authors included a survey of structured group problem solving practices used in industry for concurrent engineering and a review of computer-aided group problem solving methodologies and technology. They found only limited applications of computer-aided group problem solving to engineering design. A notable exception that apparently had broad application was the Boothroyd and Dewhurst Design for Assembly (DFA) methodology, which many companies have used to support concurrent engineering teams. Based on this finding, the research team hypothesized that the conceptual approach of DFA could be used for early supportability assessment by a concurrent engineering team that included the customer (the Air Force). Using the computer support of the Computer-Aided Life Cycle Engineering (CALCE) system for electronic design, the team developed a methodology for balancing the use of redundant parts in a product with scheduled maintenance visits in order to achieve an operational failure-free system at a low life cycle cost (LCC). The results of this research are recorded in *Computer Support for Conducting Supportability Trade-Offs in a Team Setting* (Cralley, Dierolf, and Richter, 1990).

Sometime during FY 1988-89, the ULCE program was incorporated into the Air Force portion of the Department of Defense concurrent engineering efforts. The ULCE program was one of several programs that worked toward integrating life cycle factors into the early design phases by focusing on single features, known as theilities, e.g.,

reliability, maintainability, supportability, producibility. This approach ultimately led to the institutionalization of separate terminology and analysis methods and to the formation of stovepipe functional organizations in industry and government (Aeronautical Systems Division (ASD), 1990a). As stated in The Pymatuning Group report (1988), "This 'single feature' or 'ility' approach has unfortunately been conducive to separate, non-interacting program offices and separate budget line items in the DoD acquisition process each directed to a 'single feature improvement' objective. In addition, it has led to a cumbersome, sequential, and prohibitively costly, sub-optimized procurement process." Concurrent engineering offers the opportunity to escape this single feature mentality. In FY 1990, IDA was tasked to extend the previous work in computer support for concurrent engineering teams and their meetings. This paper presents the results of that task.

B. APPROACH

The authors approached this research with a problem-oriented perspective. Their first objective was, in general, to develop a clear understanding of concurrent engineering and, more specifically, to learn how concurrent engineering teams are organized, managed, and supported--both overall and in their team meetings. While all descriptions of concurrent engineering include the characteristic of the multifunctional team, little is written about how these teams are organized and managed. There is, however, much information on teams and team meetings in the TQM and business management literature. The IDA researchers reviewed this literature and compiled an annotated bibliography, which is included in Volume II of this paper.

To obtain information on how industry is implementing the team approach in concurrent engineering, the research team reviewed the literature, attended various conferences, and visited several defense contractors: McDonnell Douglas Helicopter Company in Mesa, Arizona; Northrop Aircraft Division in Hawthorne, California; Lockheed Aeronautical Systems Company (LASC) in Burbank California; General Dynamics Land Systems (GDLS) in Sterling Heights, Michigan; and McDonnell Douglas Aircraft Company (McAir) and McDonnell Douglas Missile Systems Company (MDMSC) in St. Louis, Missouri. Many of the statements made in this paper derive from specific lessons learned by concurrent engineering teams at the different companies. Whenever possible, the authors attribute the information to specific organizations.

C. REPORT OVERVIEW

In 1989, Dr. Robert Costello, then Undersecretary of Defense (Acquisition), wrote a memorandum (Costello, 1989) endorsing concurrent engineering. The memo, titled *Concurrent Engineering - A Total Quality Management (TQM) Process*, stated, "This integrated process, i.e., concurrent engineering, resulted from each of the firms [studied by the DoD/Industry Task Force on Concurrent Engineering] having practiced TQM principles to redesign their own engineering processes." Chapter II elaborates on the relationship between concurrent engineering and TQM.

Chapter III presents what the researchers learned about the organization and management of concurrent engineering teams and their meetings from their review of the literature and visits to defense contractors with concurrent engineering activities. The companies examined for this research each organized and managed their concurrent engineering teams differently, and the authors endorse the view that there is no one right way to do concurrent engineering. The information in Chapter III can give useful insights to a company implementing concurrent engineering, but each organization must adopt the team management principles with respect to its own culture.

Chapter IV describes how the computer can improve the productivity of concurrent engineering teams when they are meeting face-to-face. This particular use of technology has not previously been addressed by the concurrent engineering research community.

Chapter V concludes the report with a summary of the findings and research recommendations.

Volume II of this paper contains annotated bibliographies of the literature reviewed for this study. The subjects are TQM, concurrent engineering, Quality Function Deployment (QFD), and group problem solving.

II. CONCURRENT ENGINEERING AND TOTAL QUALITY MANAGEMENT

In 1988, the Office of the Assistant Secretary of Defense for Production and Logistics sponsored two studies that examined how concurrent engineering might be applied to weapons system acquisition. IDA performed one of these studies and published *The Role of Concurrent Engineering in Weapons System Acquisition* (Winner, *et al.*, 1988). Winner, *et al.*, defined concurrent engineering as follows:

A systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule and user requirements.

The other study was conducted by The Pymatuning Group. Their report, *Industrial Insights on the DoD Concurrent Engineering Program* (1989), defines concurrent engineering as--

"... the set of methods, techniques and practices that:

- Cause significant consideration within the design phases of factors from later in the life cycle,
- Produce, along with the product design, the design of processes to be employed later in the life of the product,
- Facilitate the reduction of the time required to translate designs into the fielded products, and
- Enhance the ability of products to satisfy users' expectations and needs."

An essential element of concurrent engineering is good design engineering management . . ."

These definitions identify desirable results of concurrent engineering. These definitions do not, however, emphasize the relationship between concurrent engineering and TQM--a relationship that is evident within the reports. The authors of the IDA report found that improving quality was a recurring theme among the companies visited for their industry case studies (Winner, *et al.*, 1988). They wrote:

Without the emphasis on quality that characterizes TQM [Total Quality Management], concurrent engineering will not achieve its goals. In fact, every company visited during this study has either begun to implement its own TQM program or has developed an in-house quality improvement program that is basically equivalent.

The Pymatuning study also states, "Concurrent Engineering practices are an integral part of quality management and quality engineering." Another recent IDA report (Pennell and Akin, 1990) states--

Of the many methods associated with concurrent engineering, some of the most striking come from the quality community. In gathering information for this report, the authors found that quality initiatives are inseparable from concurrent engineering.

TQM is a management philosophy that involves participation by everyone in an organization to achieve customer satisfaction through continuous improvement. TQM focuses on error prevention and the elimination of waste. To be successful, it must not be viewed as a program with a beginning and an end but rather as a new way of doing business. Organizations must practice TQM much like race car builders practice their profession--continually improving their methods and adapting to change. These are all desirable attributes for an organization practicing concurrent engineering as well. TQM stresses building quality into all of the processes of an organization, whether the organization performs one or a combination of the functions of defining, building, or servicing products for its customers.

This chapter expands on the relationship between concurrent engineering and TQM by showing that the fundamental characteristics of organizations practicing TQM are consistent with and desirable for organizations wanting to implement concurrent engineering. Commonly described characteristics of organizations subscribing to the TQM philosophy include:

- A process orientation and a commitment to continual improvement.
- A focus on customer satisfaction.
- A scientific approach to problem solving.
- An emphasis on human resources and teamwork, including continued education and training.
- Strong management commitment and leadership.

The following sections describe these characteristics, elaborating on TQM applied to product and process definition (concurrent engineering).

A. A PROCESS ORIENTATION AND A COMMITMENT TO CONTINUAL IMPROVEMENT

A fundamental concept of the TQM philosophy is acknowledging the process. Any organization, whether a manufacturing firm, a service or research organization, or a consulting firm, accomplishes its mission via processes. A process is an orderly set of tasks that results in a particular outcome (e.g., service, product, information). Each process has suppliers that provide the process resources and customers that receive the process results. The people responsible for the tasks within the process are the process owners. Process owners are both customers (of their suppliers) and suppliers (to their customers). A basic TQM tenet is that true increases in productivity come from improving the processes, not controlling and managing according to the results of the processes. Furthermore, by improving the work processes, flexibility can be built into an organization—flexibility needed to cope with rapid change caused by increasing complexity and changing technology.

Continual process improvement is the progressive response of an organization to the continual change in the business and technological environments. All processes can and should be subject to continual improvement efforts. A series of small incremental improvements over time add up to major gains in process efficiency and effectiveness and assures that the organization keeps pace with the changing environment. Everyone in an organization must recognize that any process can be improved, even if the results of the process are judged to be adequate by current standards. A climate of continual improvement comes when each worker questions the standards and asks "Is there a better way?"

Concurrent engineering involves the definition of the manufacturing and support *processes* in parallel with the product definition. The implementation of concurrent engineering is an improvement of both the product and process definition processes. Continuous improvement of the design process is explicitly cited as one of "The Ten+One Commandments of Concurrent Engineering" in a recent *CALS Report* (1990). One of the first steps in improving the process is understanding it. All of the companies visited during this study put considerable effort into documenting their product development process in order to analyze it and find ways to improve it. One of the fundamental improvements observed in most companies is the adoption of a phased, parallel release of the product and manufacturing process descriptions. Early, incomplete (tentative and fragmentary) information is allowed to move between the definers of the product and the definers of the manufacturing processes instead of waiting for the official transmittal of a formal drawing

of the complete product design. In this way unworkable alternatives are eliminated early in the process, and a flexible manufacturing process that can respond to changes quickly is developed (Hayes, Wheelwright, and Clark, 1988).

B. A FOCUS ON CUSTOMER SATISFACTION

The primary goal of TQM is satisfied customers. Two types of customers are defined: external customers that purchase the goods or services of the organization, and internal customers who receive the results of other employees' work. For example, the manufacturing division of a company is considered an internal customer of the product definition group. Customers are satisfied with products that meet their quality standards and are delivered when they need them. External customers also require a price they believe is fair. The key point is that adequate quality, reasonable cost, and acceptable delivery date are defined by the customer--suppliers must understand their customer's needs.

Concurrent engineering has 4 customers: the end user of the product being developed, the manufacturer of the product, the service organization that will support the product, and the organization that will dispose of the product. The manufacturing and support planners (the internal customers) have representatives on the concurrent engineering team to assure that the needs of the manufacturing and support organizations are met. The concurrent engineering team learns the end user's need at the start of product and process definition by the generation of requirements. These requirements must be tracked throughout the product and process definition to assure that the needs of the external customer are met. Ideally, the customer is a member of the team. "Since customers often do not understand the subtleties of their needs and even more frequently the limits of technology, realistic product development becomes a problem solving process among multiple customers and multiple functional experts working as a team" (ASD, 1990a).

As an example, the General Dynamics Land Systems (GDLS) M1A2 (Abrams tank) concurrent engineering team stresses the importance of their customers' involvement. A Captain and a Sergeant, responsible to the Commanding General at Fort Knox, are located on site with the concurrent engineering team and participate daily in the team activities. Requirements definition for the M1A2 was a team process with the Army, and over 100 people from the Army participated in a system design review.

C. A SCIENTIFIC APPROACH TO PROBLEM SOLVING

TQM promotes the scientific approach to problem solving, which is a systematic way to understand, learn about, and improve processes. "It means agreeing to make decisions based on data rather than hunches, to look for root causes of problems rather than react to superficial symptoms, to seek permanent solutions rather than rely on quick fixes" (Scholtes, 1988). Practitioners of TQM use sophisticated statistical and experimental methods as well as some basic techniques for planning and tracking the processes. These techniques emphasize graphics to assist the team in visualizing the process.

In concurrent engineering, such an approach is essential to thoroughly understand the interrelationships among the defining, building, and supporting phases of a product's life cycle. Such techniques as experimental design, simulation modelling, and mathematical analyses seek to provide a deeper understanding of these relationships and determine root cause effects. For example, reliability engineers in the traditional, sequential design process performed analyses on a proposed product design to determine whether the design met the reliability specifications. The result of the analyses was typically, a yes or no answer. Under concurrent engineering, the reliability engineers must learn to take a different approach to their task and solve a different type of problem. They need to determine the root causes of predicted failures and suggest changes in the design that will lead to a more reliable product.

D. AN EMPHASIS ON HUMAN RESOURCES AND TEAMWORK, INCLUDING CONTINUED EDUCATION AND TRAINING

A fundamental tenet of TQM is that an organization's most valuable resource is its people. In an organization embracing TQM, everyone contributes to process improvement. An atmosphere of mutual trust and respect exists in which employees are motivated to identify improvement opportunities and to participate in analyzing and determining improvement strategies. Teams of employees are often used for improvement activities since teams bring a greater sum knowledge to bear on the problem, provide mutual support for their members, and establish informal communication channels throughout the organization.

A multifunctional team, consisting of specialists from all relevant departments of the corporation (e.g., engineering, manufacturing, finance, marketing), is an essential element of concurrent engineering. Most of the literature on concurrent engineering emphasizes that the external suppliers or subcontractors as well as customers or end users should be active members of the concurrent engineering team.

The major benefit of this teamwork is enhanced communication among the product developers, their suppliers, and their customers. An atmosphere in which team members can "work as equals in a climate of trust and ownership to incrementally refine the definition of the product and its manufacturing and support capabilities" must be cultivated (ASD, 1990a). As Hayes, Wheelright and Clark warn in their book, *Dynamic Manufacturing* (Hayes, Wheelright and Clark, 1988),

Many companies see technology as the answer to their competitiveness problems. The new technologies, however, demand more--not less--of workers and managers in order to achieve their potential. Somewhat paradoxically, as processes become more sophisticated and more automated, success is becoming less a matter of substituting technology for people, if it ever was. Instead, human skills must be developed simultaneously with computer software and equipment hardware, and managed in such a way that they reinforce each other.

A cornerstone of this emphasis on human resources and teamwork is training in the underlying philosophy of continual improvement, the tools and techniques of the scientific approach to problem solving, and the skills required to work effectively in a team setting. In many organizations, part of the training program is job rotation. This approach not only provides a more qualified, robust work force, but engenders unity within the work force as workers gain an understanding of their co-workers' duties and responsibilities. Training in the scientific approach to problem solving includes training in measurement and statistics. Training in problem solving enables the work force to identify, analyze, and select improvement opportunities and strategies.

All of the above training is required for concurrent engineering, but because of the multifunctional nature of the concurrent engineering teams, cross-functional training of team members becomes especially important. Because of the functional divisions in traditional organizations (e.g., design, reliability, maintainability, quality assurance, manufacturing), each functional group has developed its own language (both technical terms and jargon) over time. These specialty languages make cross-functional communication very difficult. Learning about functions other than their own enables the team members to communicate effectively. If team members cannot cross-train through actual job rotation, they must receive training to acquaint them with the functions performed and the technical terms used by the other team members. Teamwork is enhanced when the language barriers between the functional groups are overcome.

One of the teams that shared their lessons learned for this research project found that a lack of training in group dynamics led to varied participation and unequal understanding of responsibilities among team members. One of their lessons learned is that

the degree of participation of a team member is based on their innate group interaction skills or on skills learned either in organizations such as Toastmasters International or in college. This team also found that discussing what a team is and what it is not at the first or second meeting was helpful, and recommended TQM training for all team members before concurrent engineering teams begin work (Little, 1990).

Another of the concurrent engineering teams consulted in this study received no special training in team work for the concurrent engineering project, although many of the team members received some team training during previous participative management initiatives, e.g., Quality Circles, in the organization. The organization did, however, institute extensive cross-training and job rotation and trained team members from all disciplines in corporate standard design practices and the use of the corporate Computer-Aided Design (CAD) system (Stevens, 1990).

E. STRONG MANAGEMENT COMMITMENT AND LEADERSHIP

It is the role of management to create and foster the organizational culture for TQM that allows people to focus on quality and continual improvement. Managers must become coaches whose purpose is to provide workers the requisite resources to continually improve their assigned job. Management must set the strategic vision and goals for the organization so that the entire organization, down to the individual worker, can relate their daily efforts to the organization's mission.

Whether organizational change is slight or significant, management commitment to concurrent engineering is essential. Changes at McDonnell Douglas, for example, began with an executive commitment for research followed by an executive commitment to change. The levels of management were reduced from nine to five. Often the implementation of concurrent engineering begins with a specific project as a test bed, but the project needs the sponsorship of a vice president or general manager. The case studies in the IDA report on concurrent engineering (Winner, 1988; Appendix A) all emphasized the need for strong management involvement for the success of the concurrent engineering efforts.

It is up to management to create an organizational structure and resulting organizational climate in which a TQM approach to product and process definition can survive and flourish. For concurrent engineering to work effectively, there must be teamwork among the product and process definition team members, open lines of communication among the team and throughout the organization, and commitment on the

part of management to provide adequate resources (time and money). The following chapter describes some team organization and management practices to accomplish these goals.

III. ORGANIZATION AND MANAGEMENT OF CONCURRENT ENGINEERING TEAMS

This chapter presents many of the issues that must be considered for the efficient functioning of concurrent engineering teams. These issues and ideas pertain not only to concurrent engineering teams but also to many different types of teams with slight variations. Generally, there are many attributes that may vary among the different types of teams. These include--

- The capabilities and status of the members.
- The size of the team.
- The homogeneity of the members.
- The transient or permanent nature of the team.
- The complexity of the problem the team has to solve.
- The time constraints for determining the solution.

Problem solving in product and process definition of complex systems goes beyond decision making--it includes defining the problem, generating alternative solutions, evaluating alternatives, selecting alternatives, and implementing the solution. The problems are multileveled, multidimensional, and multidisciplinary--all of the information required to form a solution may not be available, and the available information may be based on judgment and experience. The design of complex systems involves human interaction among engineers with various backgrounds and from various disciplines. When multiple measures of merit for judging the level of acceptability of a design exist, all *may* not be equally important to the functionality of the design, but certainly all *are* not equally important to each individual member on the concurrent engineering team (Mistree and Muster, 1988; Muster and Mistree, 1988).

The success of each concurrent engineering project clearly depends on the ability of the team members to work together; thus, total team satisfaction with the process and the resulting product and process definition is pivotal. Achieving consensus among members of a concurrent engineering team means arriving at a product and process definition that every member accepts (Doyle and Strauss, 1982). Each member may not think a design is the absolute best attainable, but in agreeing to a particular design, each member must

believe that it is a good design and that all essential design elements have been included. Having all members satisfied with the design ensures ownership and responsibility among team members. Once consensus is achieved among the team members, it is essential that buy-in is achieved from the team sponsor and upper managers. The preferred method is by maintaining open communication during the process to prevent management objections during the implementation phase.

The multifunctional nature of the teams complicates the group dynamics because of the language barriers, perceptions of unequal status, and general cultural barriers to teamwork. The GDLS M1A2 concurrent engineering team has developed a list of specific obstacles that challenge management in promoting effective product and process definition (Tierney 1990):

- Engineering division members see themselves as creative individuals who do not want that creativity restricted by having to accommodate all functional concerns.
- Manufacturing division members have to satisfy customers' current orders and maintain stability.
- Rigid, functionally dominated organizational structures exist.
- Everyone's organizational base becomes the center of their universe.

Management must overcome these obstacles if the definition process is to work effectively. Various methods and management practices exist to overcome these difficulties and accomplish the concurrent engineering approach to product and process definition. This chapter describes some of the various organizational and management strategies industry is practicing to fully utilize teamwork in product and process definition.

A. CORPORATE ORGANIZATIONAL STRUCTURE

As products became so complex that a single designer or even a small group of designers could no longer efficiently design them, many large companies chose to organize around specific functions and accomplish projects using a matrix type of structure. Professor John Mee defined a matrix organization in 1964: "A matrix type of organization is built around specific projects. A manager is given the authority, responsibility, and accountability for the completion of the project in accordance with the time, cost, quality, and quantity provisions in the project contract. The line organization develops from the project and leaves the previous line functions in a support relationship to the project line organization."

Under this form of management, the personnel in an organization are aligned by functional groups, comprising the vertical columns of the matrix, and projects are accomplished by assigning one or more individuals from each functional group to each project, comprising the horizontal rows of the matrix. One problem with this type of organization is that the project engineer, who has to rely on team members from the different functional groups, typically has little authority over those people. Team members are loyal to their functional divisions where they are evaluated, compensated, and considered for promotion. This functional division separates the specialty engineers from each other as well as from the designers--the most notable separation occurring between the engineers and the manufacturing personnel. To alleviate the difficulties associated with the traditional corporate organization, engineering companies are considering various organization models from diverse fields. Northrop Aircraft Division (NAD) has studied the organizational design literature and based on a widely shared organizational model (Galbraith, 1977; Beckhard and Harris, 1987; Lawrence and Lorsch, 1967; Hanna, 1988) has developed strawman guiding principles for the teams. These guiding principles covered basic strategies and systems to be used by the concurrent engineering teams to design their operating processes.

Some companies have decided that functional alignment is not the most conducive structure for the product and process definition team effort and are experimenting with different organizational structures for implementing the concurrent engineering approach to product development using a multifunctional team. McDonnell Douglas has essentially shifted the matrix organizational chart 90 degrees to align their organization by product lines and allow the product line managers to evaluate employees. McDonnell Douglas has also established a support division (a vertical column alongside the product lines) that is responsible for providing the horizontal ties of the corporate-wide processes and improving them. Members of this division are paid entirely out of overhead. The horizontal integration is related to process, the vertical integration is related to product.

Other companies have found that functional alignment does not hamper their concurrent engineering efforts (Huthwaite, 1990). In fact, functional alignment offers advantages when subsystems or components are not unique across product lines, such as when product compatibility or parts commonality is beneficial (Hayes, Wheelwright, and Clark, 1988). Huthwaite calls implementing concurrent engineering teams within the traditional corporate structure "Teamwork within the Tradition." Multifunctional project engineering teams are formed of people from the various functional groups, such as manufacturing, reliability, design, and quality engineers, augmented with purchasing

personnel, suppliers, and users. These teams direct and integrate all technical aspects of the design and development process of a product and in general have more responsibility, authority, and accountability than project teams in the past. More authority also rests in the hands of the project leader. Team members report to the project leader, who reports to upper management. Obviously this type of arrangement may threaten some functional managers, who see it as a usurpation of their authority. This is one of the cultural barriers that must be overcome for concurrent engineering teams to be successful in traditional organizations.

GDLS is functionally aligned, and its approach to concurrent engineering for the M1A2 appears to be very successful. The concurrent engineering team functions as a systems integration team whose individual members are also members of the product and process definition teams. In implementation, the Chief Engineer, responsible for the Technical Data Package, and the concurrent engineering lead of the GDLS M1A2 project both report to the same level of management. One of the lessons learned by this team was that people often encumber the concurrent engineering process with the excuse "there's not enough time to do my function and share in concurrent engineering." Organizational policies and practices (including those for performance review and promotion) must foster the attitude that concurrent engineering and TQM are everyone's job.

B. TEAMS OF TEAMS

A general rule for effective group interaction is that the group's size not exceed 8-12 members. However, the development of a complex product can require hundreds of people from various functional groups in an organization. The complete concurrent engineering team performs, therefore, as a team of teams. The use of the word team here has more to do with a way of thinking about a problem than the size of the group. "A *team* consists of professionals who operate from a shared agenda and a common view of their assignment" (Heany, 1989).

The team of teams is usually a hierarchy of teams that follows the decomposition of the physical product into zones or subsystems for the product and process definition. Aligning teams according to the work breakdown structure (WBS) has been suggested (Meyer, 1990). The term hierarchy here does not apply to the status of the teams or team members but rather to the relationships among the teams and how these relationships correspond to product and process definition responsibility. Communication can be maintained among teams by placing a member (usually the team leader) from a lower level team on a team at the next highest level. The high-level team resembles a systems

engineering team that defines the integration of the results of the other teams. "Systems engineering in this case is not intended to be a 'specialty' itself. Instead, it provides the framework to manage integration of the development process of the product and its manufacturing and support processes" (ASD, 1990a).

There is usually at least one team for each node on the decomposition of the product. If the product and process definition of the subassembly or zone requires more than a dozen people, the teams are further divided by discipline or technology (e.g., composites, electrical, avionics). The decomposition occurs until the subsystems can be defined by a manageable group (8 to 12 people). For example, the McAir Integrated Product Teams (IPT) are organized by disciplines within the product center. The theory behind organizing the teams along discipline or technology lines either within the product center or subsystem is that grouping people by discipline is a way to break the language barrier so often encountered when people who have traditionally performed different functions try to communicate. Most members of the same discipline speak the same language, regardless of their function. For example, mechanical engineers, whether from the engineering, manufacturing, or support group, will understand most of one another's technical terms because of common education.

McDonnell Douglas Missile Systems Company (MDMSC) uses seven concurrent engineering teams for the Advanced Harpoon Block 1D project: four product development teams (Missile, Cannister, Test Articles, and Ground Support Equipment) and three process teams (Machine Parts, Tooling, and Procurement). A Steering Committee consists of the seven team leaders and some specialists. The Steering Committee meets to discuss the teams' activities and any problems, and is responsible for the concurrent engineering procedures and cross-communication among the teams.

Lockheed Aeronautical Systems Company uses a variety of team organizational structures, depending on the size of the project and the specific product being developed. The Composite Development Center (CDC) management uses small round-table teams for smaller projects and problem solving. They use Zone Management in the design of the P7A Patrol Aircraft, a much larger project than those projects in the Composite Development Center. Zone management is a technique whereby the physical product being designed is divided into physical zones. Each zone has its own product and process definition team, responsible for all of the requirements within its zone, and an additional team has the systems integration responsibility for all of the interfaces between the zones.

Problem solving teams can be formed to address specific problems encountered. These teams may or may not be multifunctional. A good example of a problem solving team, whose experiences led to practical lessons learned, was the Systems Integration Engineering (SIE) Avionics Rack Commonality Working Group, a multifunctional team organized to solve an avionics rack commonality problem at NAD. Another type of team used by organizations practicing concurrent engineering is one that functions as a TQM process improvement team, concentrating more on improving the *process* of product and process definition than on actually doing product and process definition.

C. TEAM MANAGEMENT

Successful management of a team relies on the same types of effective policies and actions that make management of an organization successful. A team is, after all, a small organization. Following are some of the activities essential to effective team management (Heany, 1989; Cleland and Kerzner, 1986):

- Structuring of the team's organizational design, i.e. the roles, responsibilities, authority, and accountability that people are expected to have.
- Preparation of a clear, concise team charter or mission statement stating the problem the team is to solve and the boundaries or limitations imposed, including the schedule and the cost of their process.
- Identification of the goals or milestones (characterized by specificity and time-based measurement points) that the team is expected to accomplish in working toward its mission or purpose.
- Identification of the tasks required to accomplish the team's purposes.
- Delineation of the strategy of the team to include major policies, programs, procedures, plans, budgets, and other resource allocation methods required to facilitate its operation.
- Identification of human and nonhuman resource support and authorization of the development and improvement of systems that allow team members to get their job done.

The distinctive features of team goals are their specificity and time-based measurement points--they tell the team the magnitude of the progress they are expected to make (Scholtes, 1989; Cleland and Kerzner, 1986). Completion of all of the goals within the given resources will accomplish the team's mission. Goals can be assigned to individual people or to groups of people on the team. The team must make use of both human and nonhuman resources.

Trainers and facilitators are fundamental human resources to the team. Other resources include the technical and computer support. Technical support should include the design, development, and implementation of information systems to track and report the team progress. In addition, the design and implementation of a control system may be needed to monitor the team progress and, when necessary, reallocate resources to more effectively accomplish team objectives and goals (Scholtes, 1989).

For the concurrent engineering team for the Advanced Harpoon Block 1D missile improvement at MDMSC, a complete documentation package, prepared and distributed to the team members before the initiation of team activities, included--

- A cover memo, signed by management at the vice president level, explaining responsibilities.
- The team organizational chart, showing the relationships among the teams.
- The team definition and required deliverables, including a matrix of the deliverable drawings vs. the disciplines of the team members illustrating team membership. The composition of the team, however, was allowed to change at any time under the direction of the team.
- A Memorandum of Agreement (MOA), containing the philosophy behind the team effort, the procedures for charging time, and the duties of the team members.
- The draft Standard Procedures, defining the operational processes to follow and the computer systems to use.
- The schedule.

Similarly, a Team Management Package was prepared for the SIE working group at NAD before the work of the team began. This package consisted of a vision statement, the charter, the goals of the team, the initial membership roster, the responsibilities matrix for the technical leader and facilitator (see Section D.1.), a Quality Function Deployment (QFD) matrix, and the task completion schedule. A detailed schedule chart (e.g., Gantt chart) was not included, and the group learned, as a result, that a schedule of this type is essential to avoid false or missed deadlines. The group recommended that the QFD tasks be tied to schedule line items in either a Gantt or a critical path format. However, they cautioned that the team goals and schedules must be open for redefinition as the issues and the risks change during the project. The team must have a certain amount of flexibility for success.

Regardless of the type of organizational structure selected for concurrent engineering team formation, each team needs to have a sponsor. The team sponsor can be

either a person or a team of people at the management or supervisor level, such as a vice president or a steering committee. For projects that involve more than one company, the sponsor team should involve individuals from all the companies involved. For example, NAD has formed a management team at the highest level with representatives from the two principal companies, NAD and McAir, involved in its Advanced Tactical Fighter (ATF) program. This management team is the sponsor of all product development teams involved on the program.

The team sponsor supports the team's activities, secures resources, and opens communication lines between the team and the rest of the department, the division, and the organization. Sponsors should possess a personal stake in the success of the concurrent engineering effort, control over the resources needed to launch and sustain the effort, and the authority to empower the team and remove any roadblocks to its success (Heany, 1989; Cleland and Kerzner, 1986). The sponsor can do much to help the concurrent engineering team overcome inefficient processes imbedded in the culture of the organization. For example, a reason might once have existed for extensive paperwork between people on a project team. With concurrent engineering, many decisions can be reached through the face-to-face interaction of the team members. The extensive paperwork may no longer be needed, but not only is it required by the organization's business practices, it is instilled in the cultural practices of the team members (Gross, 1990). The sponsor should help remove these inefficiencies to the process.

D. TEAM MEMBERSHIP

Much of the success of a team is determined by the choice of team members. Concurrent engineering teams may involve both blue collar and white collar, union and non-union workers. "Achieving the required level of teamwork requires a structured process and competent people with specific expertise and understanding of the product line, users, technology base, materials, manufacturing capabilities, support capabilities and the acquisition process" (ASD, 1990a). The Memorandum of Agreement for the concurrent engineering team for the Advanced Harpoon Block 1D improvement at MDMSC stated that the intent for team membership is "to include only those individuals who can evaluate the soundness of the design and viability of the manufacturing process of each part or assembly (including: inspectability, testability, reliability and maintainability, procurement, and production)" (Stevens, 1990). Individuals should be chosen for team membership who (Heany, 1989)--

- See themselves as responsible, at least in part, for the quality of the product.

- Believe their expertise is relevant to the product and process definition.
- Believe the expertise of the other team members is relevant to the product and process definition.
- Can be trusted to approach the product and process definition beyond a narrow functional standpoint.
- Possess technical competence in their special function and the know-how to gain access to data or additional technical advice when needed.

One of the lessons learned by the NAD SIE group was that the critical factor for membership on the team is ownership of the problem. The people selected for a team must be those who are affected on a daily basis by the problem being addressed by the team. The criterion proposed for selection is "the more pain the better." Ownership of the problem motivates team members to develop quality solutions; even if they will not be responsible for directly implementing a solution, they will be affected by the solution.

Many of the members from the manufacturing and support functions receive an additional benefit by participating in the product and process definition team--their own jobs may be easier to perform or their own efficiency may increase. By participating on the team, these members no longer have to wait for a completed design before they can perform their job. As team members, they provide continual design influence. In general, members of a concurrent engineering team find the experience to be both stimulating and difficult. Enthusiasm for the process was evident at all of the companies that the authors visited for this study.

Since the GDLS M1A2 high-level concurrent engineering team is primarily a systems integration team whose individual members sit on various product and process definition teams, the team members spend most of their time communicating. GDLS has found that managers are the best choices for this high-level concurrent engineering team. These managers have served as the facilitators for the total concurrent engineering team of teams, and their positions have helped them surface problems to bring to the attention of the teams. GDLS has supplied these managers with additional administrative support so that they have the time to adequately perform their concurrent engineering function. The product and process definition teams or the problem solving teams normally comprise non-management people, because they are actually doing the definition work.

The formation of a product and process definition team carries with it no guarantee that team members will talk to one another. The team must include the right leader, as well as the right team members. When Westinghouse Electronic Systems Group first

implemented concurrent engineering, the manufacturing people did not persevere in pointing out problems they saw in the design, perpetuating the notion that engineering design was the kingpin function of the organization. In all organizations, management must cultivate an atmosphere that allows people to perform as equals on the teams. Westinghouse eventually cultivated such an atmosphere and as a result successfully redesigned a wired chassis assembly for the Airborne Self-Protection Jammer (ASPJ/ALQ-165) (McAfee, 1990).

1. Team Leadership

The team leader is the team member responsible for managing the team. His or her duties include (Scholtes, 1989)--

- Calling and directing all team meetings.
- Orchestrating all team activities.
- Overseeing the preparation of reports, presentations, meeting agendas and minutes.
- Handling or assigning administrative detail.
- Ensuring timely analysis and resolution of technical decisions.

Team leaders are often supervisors or managers and are usually responsible for the technical content of the product and process definition. The team leader is a full-fledged team member who shares the responsibilities of attending meetings, carrying out assignments between meetings, and generally sharing in the team's work. In addition, the team leader is the point of communication between the team and the rest of the organization, specifically the team sponsor.

The product development teams at NAD have two leadership roles--product and process--performed by the Technical Leader and the Facilitator, respectively. Both the technical leader and the facilitator are responsible to the Management Team. The technical leader has the responsibility for the technical package that will be delivered at the end of the team deliberations, and the facilitator has the responsibility for the administrative package. The technical leader and the facilitator of the NAD SIE group worked together to generate the initial membership list prior to the first meeting. This list was reviewed and open to modification throughout the life of the team as priorities and risks in the project changed. The team found involvement of all necessary people essential because working with an incomplete membership results in discord between divisions (or companies) and among team members.

2. Collocation¹

One organizational element that has proven successful for many of the concurrent engineering teams is collocation of the team members. The benefits of the collocation include (Little, 1990)--

- Fostering of informal communication among team members.
- Reduction in functional allegiance, adversarial relationships.
- Cultivation of flexible relationships, appreciation of each other's concerns.
- Creation of a participative atmosphere in the work place.

Often the collocated members of concurrent engineering teams change over the duration of the project. (At all times, however, each team member remains responsible and accountable for the product and process definition.) As its work progresses, the concurrent engineering team may recruit new people to solve specific problems. Originally all the team members may be collocated, but as the size of the team grows, collocation of all the new members may not be possible. The GDLS M1A2 concurrent engineering team began with about 22 people and grew to include about 100 people. Originally all the team members were collocated (same building, same floor), but as the size of the team increased, collocation of all the new members became difficult. At some point a concurrent engineering team (team of teams) may become so large that many of the benefits of collocation are no longer realized--a person is limited in how many other people he or she can informally communicate with in any given time period.

With Zone Management at LASC, all the team members of a particular zone are collocated to facilitate daily communication. The concurrent engineering teams at MDMSC and McAir are also collocated as much as possible to ensure that team members learn about other members' concerns by talking directly. (If a team member spent more than half their time on the Block 1D effort, they were collocated with the group.)

An obstacle to the easy implementation of concurrent engineering in many current weapon system programs is that the product development involves not only many functional divisions in one company, but also many different companies. Collocation was deemed so important for the work on the Light Helicopter Experimental (LHX), that Bell Helicopter Textron, Inc., relocated people from Texas to Mesa, Arizona, to be on site with McDonnell Douglas Helicopter Company.

¹ This is the spelling of the word in the dictionary that means "to set side by side." Many people prefer to use the term co-locate.

E. TEAM MEETINGS

Effective team meetings are one of the team's best opportunities to enhance the team building process and make progress toward accomplishing the team goals. To enhance the effectiveness of team meetings, the following procedures are recommended (Heany, 1989; Cleland and Kerzner, 1989):

- Limit the duration of team meetings--three to four hours at most.
- Use agendas and record minutes.
- Do not end a meeting without specifying and assigning the action items.
- Let no more than two weeks elapse between meetings.
- Insist on attendance of all relevant parties.
- Allow no phone calls or other interruptions during a work session.

One of the companies consulted for this study pointed out that when conducting regularly scheduled meetings, people attempt to do everything inside the meeting. It is important for the team to take care of those items that need all the team members' knowledge during the meeting, but team members must realize there is still a lot of work to do outside of the meetings.

Discipline is an important element contributing to the success of concurrent engineering team meetings and, thus, to the team itself. Companies emphasize that each meeting should be held for a purpose and not merely just to have a meeting. The regularly scheduled meetings of the concurrent engineering teams at MDMSC started out at once a week for one hour. The frequency of the meetings is flexible, however, based on the team leader's judgment. Even when concurrent engineering teams meet every day, such as for the GDLS M1A2, the meetings are focused. Meeting activities are strictly limited to the agenda items, and all of these activities have a deliverable focus. In addition, what is said is strictly recorded. Such meeting documentation should exist for all of the meetings as well as the management and program reviews. The following sections elaborate on some of the critical elements to team meeting success, and the next chapter describes computer support that could contribute to that success.

1. Agenda and Minutes

All companies visited for this study attributed the success of their team meetings to the discipline attained through the strict adherence to a meeting agenda and the reliable preparation of meeting minutes. The agenda is prepared by the team leader and distributed

to team members in advance of the concurrent engineering team meetings. The agenda includes the scheduled action items, the presentation items and times, and the meeting attendee requirements, based on the action items to be covered at the meeting. At MDMSC the team members are empowered to decide whether they are needed at the meeting or not. The team leader has the right to invite those he deems should be present at the meeting.

The minutes of the meeting contain the action items with their status, the closure dates, and the assignees. After each meeting the minutes must be completely and promptly compiled, printed, and distributed along with all presentation materials from the meeting. The NAD SIE group distributed the team meeting minutes not only to the meeting attendees but also to each team member's management and staff organizations. Team members were thus encouraged to fully participate in the meetings and provide presentations, since the members received recognition for their team performance and activities by their management. The meetings at MDMSC are open and team members can bring other personnel they feel would be productive based on the agenda items. The minutes should record the attendance of these additional or new people (Stevens, 1990). All team leaders and associated management of the various teams organized around a specific discipline received the minutes of the meetings of each team. At some level of detail, all relevant personnel need to know the activities of the other teams. As new people join a concurrent engineering team, they should receive or have access to all meeting documentation and the initial team management documents.

2. Facilitator and Recorder

The literature on effective team meetings usually describes two roles that support the meetings: facilitator and recorder. The facilitator has expertise in group dynamics and group problem solving methods and concentrates on the process of the team meeting rather than the technical content. This person performs the roles of catalyst and diplomat, defusing personal conflicts and converting differences of opinion into positive action. The ideal facilitator quickly learns to converse with team members using their terminology. A facilitator can be brought in from outside the company or selected from within the company and specially trained. Alternatively, all team members can be trained in facilitation skills, and a different team member can perform the facilitator functions at each meeting. In industry, the initial implementation of concurrent engineering usually includes the assignment of a facilitator or coach from a support division within the organization to the concurrent engineering team. These facilitators or coaches are often specially trained middle managers (Holpp, 1989) who usually have facilitation duties outside of the team

meetings as well. At NAD, the facilitator is viewed in a co-leadership role, responsible for the administrative package.

When a team member functions as a facilitator, he or she must act as a neutral servant of the team and refrain from evaluating or contributing ideas during the meeting. The facilitator's responsibilities during the meeting include (Scholtes, 1988; Doyle and Strauss, 1976)--

- Keeping the discussion focused on the topic and progressing according to the agenda.
- Intervening if the discussion fragments into multiple conversations.
- Tactfully preventing anyone from dominating or being overlooked.
- Bringing the discussion to a close.

The facilitator usually is responsible for the meeting logistics, although this responsibility may fall on the team leader.

The recorder at a meeting is the scribe who records the minutes of the meeting. Bringing in a recorder from outside the team is difficult because the recorder must have an understanding of the technical language of the team in order to summarize it and record what is important. A visual means of seeing what is recorded is valuable so that the team members can ensure that the ideas are recorded accurately. The recorder, like the facilitator, must be a neutral, non-evaluating servant of the team during the meeting, even if the duties of recorder are rotated among the team members. The recorder must be careful not to alter the meaning of any team member's contribution when capturing the key points of the meeting. The team members at the meeting have the responsibility of keeping the facilitator and the recorder in their neutral roles (Scholtes, 1988; Doyle and Strauss, 1976). The facilitator and recorder have the responsibility of arriving early and setting up the meeting room (Doyle and Strauss, 1982; Scholtes, 1989).

At MDMSC, the facilitation and recording tasks are performed by coaches who are based in a support division in the organization (Integrated Design, Manufacturing, and Support Technology) but assigned ad hoc to the concurrent engineering teams. It is the coach's responsibility to run the meetings and prepare the minutes. Between meetings the coach and the team leader work together. The coach is responsible for recording and distributing the minutes, which contain the action items, the assigned responsible party, and the due dates. Each coach records the minutes in their own preferred way--MDMSC has not found it necessary to have minutes in a standard form or recording format, although a standard form is recommended in the literature on meetings (Doyle and Strauss, 1982).

At General Dynamics Land Systems, the leader of the M1A2 concurrent engineering team has had the ultimate responsibility for all of the meeting records. The facilitator function has rotated among the team members, helping everyone develop a sense of ownership and control. The primary reason the GDLS M1A2 concurrent engineering team has kept tangible records of all team activities is that such record keeping helps the team members understand what they really did--not just what they think they did (Diaz, 1990).

3. Meeting Room

Having a single designated room for all of the team meetings helps focus the team members. The concurrent engineering team for the GDLS M1A2 has held its daily meetings in what it calls a control room. All open action items and those persons responsible are posted on the walls. The complete schedule and process diagrams are also displayed, as well as any other useful or motivational information. Having a control room helps build team spirit because it is the team's home room. They would like to have the ability to gather around a computer screen in the control room, but they currently do not have good high-resolution graphics screens available in the room (Diaz, 1990). The following chapter describes various types of computer support that could be used in the meeting room.

IV. COMPUTER SUPPORT OF CONCURRENT ENGINEERING TEAM MEETINGS

Many of the significant improvements attributed to concurrent engineering come from changes in the management of the product and process definition activities rather than advances in computer technology. If the philosophy and principles guiding the company's behavior are wrong, no amount of effort or additional resources, including automation, will keep the company competitive. However, computers will continue to have a significant role in all types of work. Improving existing applications of computer technology--and finding new ones--will certainly become part of most organizations' continuous improvement activities. A growing number of researchers are exploring ways to combine communication, computer, decision, and group process technologies and methodologies to support meetings. The computer support can be as simple as computer-controlled audiovisuals or as complex as specially designed meeting rooms with elaborate computer networks.

The traditional concept of a meeting is two or more people assembled for a common purpose. Technological advances have eliminated the need in some cases to physically assemble in a traditional meeting setting. Technology has created several new types of meetings such as:

- Teleconferencing - voice meetings.
- Video-conferencing - voice and picture meetings.
- Computer network conferencing - text and graphics meetings.

This chapter focuses on the computer's role in support of the concurrent engineering team in traditional (face-to-face) meetings. Proposed methods of introducing computer support for meetings cover a wide spectrum from the use of software designed for a single user (e.g., word processing, spreadsheets) to the use of elaborate meeting rooms that provide a computer for every participant. The basic concepts behind these approaches are presented in the following paragraphs with references to more detailed descriptions.

A. SINGLE-USER SOFTWARE

This chapter describes three approaches to computer support for meetings. The first approach is to simply use software designed for single users during a meeting. This approach is probably the easiest to introduce and certainly the least expensive. The concept is to use the same computer software during the meetings that increases the productivity of individual team members in their offices. The computer, software, and trained operator are already available and only need relocation into a room big enough to comfortably hold the team. If the computer monitor is not large enough for everyone to see, then either a larger monitor or a computer projection system can be used. Another option is to interconnect several small monitors. With this approach the computer can be used to capture and organize textual or graphical information, as a dynamic presentation device, or for performing analyses or assessments. A visual means of seeing what is recorded is valuable because the team members can ensure an accurate recording of the ideas. Many of the teams we visited expressed a desire to have a monitor in the room to view the graphics and analyses.

A good reference for this approach is Bernard DeKoven's book, *Connected Executive* (DeKoven, 1990). The primary software he promotes for use during meetings is the outline processor. As expected, an outline processor is a software program designed to create and manipulate outlines. The key feature of this type of software is the ease with which the outlines can be changed. DeKoven describes how the outline processor can be used in developing agendas, creating documents, capturing major themes from the discussion, supporting debate, and producing instant minutes. DeKoven's central strategy to facilitate the introduction of computers into meetings is the creation of a new role, that of the *technographer*. The technographer uses the computer during meetings to help a group of people focus, express, clarify, and organize their ideas. The technographer must possess more than hardware and software skills--he or she must be able to respond appropriately to the ever changing needs of the group being supported. This role is an enhancement on the role of recorder. "As the meeting facilitator is competent in techniques for facilitating the *process* of the meeting, and the [leader] has content knowledge, the technographer facilitates the product." (DeKoven, 1990)

There are many software products for personal computers that facilitate the creation of presentations. Many of these products allow the computer to be used as an electronic slide projector. Using the computer this way eliminates the need to create overheads or 35mm slides. Furthermore, the presentation material can be easily modified based on audience feedback. The Computer-Aided Design (CAD) workstation of the design

engineer using three-dimensional (3D) solid modeling is another convenient presentation device for concurrent engineering teams to use. The ability to rotate and magnify areas of interest is especially valuable in allowing the design engineer to communicate his work to the other specialists on the team.

There are few limits on this approach of using software designed for a single user to support concurrent engineering team meetings. Other ideas include using project management software or spreadsheets for budgeting and providing access to the evolving common repository of design data.

B. SINGLE-OPERATOR SOFTWARE

The second approach is the use of software designed for group decision support that resides on a single computer operated by an individual. The Decision Techtronics Group (DTG) at the State University of New York in Albany has developed an approach to solving complex problems they call Decision Conferencing. "Decision conferences are designed for groups that need to reach consensus on complex decisions for which there is no 'formula' or objective solution but, nonetheless, must be made on time, in spite of information gaps and uncertainty" (Schuman, 1987). Decision conferences combine computer-based analytic decision modeling and group facilitation methods in order to enhance the productivity of the group. In addition to the facilitator and recorder functions, a Decision Conference requires the use of an analyst to build the mathematical model from the ideas generated by the group.

Interactive Management (IM) is another computer-assisted group problem solving technique that was developed at George Mason University in Fairfax, Virginia. IM combines consensus methodologies--which provide the opportunity for focused open dialogue in structuring ideas, designing alternatives, and making trade-offs--and software, all based on sound behavioral and technical principles. The computer programs are used to efficiently derive structural maps illustrating relationships among ideas and to perform trade-off analyses with both qualitative and quantitative attributes (Christakis and Keever, personal communication). IM has been shown to effectively elicit and combine the expertise of a design team. In late 1983, a Department of Defense (DoD) tri-Service task force was formed to demonstrate the technology base feasibility of developing three different strategic defense systems. The task force worked intermittently for 6 months without producing any useful conceptual designs for the space-based laser system. The task force leader decided to try the IM approach, and after 28 hours of group work, an acceptable conceptual design was completed (Christakis, 1983).

Boothroyd and Dewhurst's Design for Assembly (DFA), a method for evaluating the ease of assembly of design alternatives, is an example of analysis software that can be used in a team setting. Questions posed by the software are answered by consensus of the product/process team (composed of both design and manufacturing engineers), but the software resides on a computer that is operated by an individual team member. The method uses quantitative analysis to focus the group's efforts and draw on the creative power and expertise of individual team members. The quantification of design factors aids the group interaction process in team design activities, since the group must reach a consensus on the measurement ratings used to assess a design alternative's ease of assembly.

The training sessions required for the proper use of DFA stress that computer tools needed for simultaneous engineering must support the human interaction that occurs during the concurrent engineering team problem solving process--stimulating the creativity and learning of team members, helping them arrive at consensus, and enabling them to make estimates when hard quantifiers are not available. Software used in a group setting must also be quick--the key to consistent measurements made by a group is rapid iteration. Used properly, the group process of using the computer tool should be as valuable as the analytical results derived from its use (Cralley, Dierolf, and Richter, 1990).

C. DECISION ROOMS

The third approach to computer support for meetings is to use computer-supported decision rooms (AIRMICS, 1989; Turner, 1989; Dierolf and Richter, 1989). These rooms, often referred to as Group Decision Support Systems (GDSS), provide each meeting participant a personal computer or terminal. Specially designed software assists the group's problem solving activities. The immediate benefit of this approach is the structure it provides to the meeting process. An eventual benefit of this approach is the possible elimination of the need for physical collocation of the meeting participants. It must be stated, however, that these rooms are best considered research laboratories. Much of the empirical research has produced inconsistent results about the benefits of this approach.

Only one of the companies visited during the course of this study had extensive plans for using computers to support its concurrent engineering team meetings. Lockheed Aeronautical Systems Company (LASC) has developed a meeting environment for its concurrent engineering teams that affords each team member access to the same computer hardware and software used in their own workspace. LASC calls this environment the Computer Integrated Manufacturing (CIM) Roundtable. While the environment is complete--including the computer network--it has had only limited use for actual design

complete--including the computer network--it has had only limited use for actual design meetings. The networking component has, however, facilitated more extensive and rapid experimentation with the solids model by the maintainability engineers, resulting in better quality preliminary design.

The concurrent engineering teams at National Cash Register (NCR) Corporation hold weekly meetings with on-screen reviews. These meetings are called limited distributed meetings because, although they are all in the same room, team members may be grouped around different computer terminals in the room. NCR Corporation has found that computer support delivering detailed design information to all team members has had both benefits and disadvantages. Such support has allowed the team members a private review of the design information at their desks, enabling them to prepare more thoroughly before the team meetings. However, having the information at their desks caused many users to throw the electronic images "over the wall" in much the same way that the engineering drawings once were in companies practicing engineering design as a sequential (instead of integrated) process. Moreover, this ability led some to believe that they did not need to attend the meetings. Vigilance is required to ensure that all team members come to all the meetings. The effective product team will move from a review-oriented process toward direct participation in product and process definition (Wallach, 1990).

V. FINDINGS AND RESEARCH RECOMMENDATIONS

Specific concurrent engineering practices vary among organizations. There are, however, various management practices that appear to work well for most organizations. This paper has presented the reader with useful examples from several defense contractors illustrating how concurrent engineering teams are being organized and managed and how concurrent engineering team meetings are conducted and supported. It has also identified types of computer support for concurrent engineering team meetings that could be used to enhance the organization and management of these meetings. Many of the applications of computer-aided group problem solving are possible and practical today.

This chapter summarizes the general findings from the study and identifies areas determined to require further research.

A. GENERAL FINDINGS

1. Relationship Between Total Quality Management and Concurrent Engineering

While one could argue that concurrent engineering can be done in organizations that do not embrace Total Quality Management (TQM), the authors found no examples where this is the case. This finding is consistent with the finding of the DoD/Industry Task Force on Concurrent Engineering that companies have attained the integrated concurrent engineering process by applying TQM principles to their engineering process (Costello, 1989). The TQM literature provides valuable information about process analysis and the use of teams for process improvement, and it should be consulted by organizations interested in concurrent engineering. Implementation of TQM should precede the implementation of concurrent engineering. TQM provides a holistic approach toward improving an organization that takes into account the people that make up the company, the corporate history, existing policies and procedures, and existing support systems. While there may be similarities, each implementation of TQM and concurrent engineering is unique in that each organization begins at a different point.

While this is not the first time this relationship has been identified, the authors have found that the promoters of concurrent engineering and TQM, both in industry and in DoD,

are often from separate organizations. It is important that the promoters of these two key initiatives recognize the close relationship between TQM and concurrent engineering and provide consistent guidance to prevent diluting resources.

2. Communication as the Key to Concurrent Engineering

The benefits of concurrent engineering are primarily derived from enhanced communication. All companies stressed the importance of clear, concise statements of the team's mission, goals, resources, and constraints; accurate but concise recording of the team activities distributed to all relevant people in the organization; and ongoing briefings of team progress to other stakeholders. The collocation of the team members allows them to communicate on a daily basis and to gain an understanding of each other's perspective.

3. Computer Support for Team Meetings

Based on the site visits and a further review of the literature, the authors stand by the finding from their 1989 report (Dierolf and Richter, 1989) that computer support for meetings represents an opportunity to enhance the effectiveness of concurrent engineering teams. There are a variety of ways computers can support concurrent engineering team meetings. In the near term this support will most likely be through software designed for single-users being employed in group settings. The more elaborate, multiple computer support systems warrant further research, especially in recognition of their demonstrated success in the face-to-face group support in business applications and their potential to support physically separated teams. A key requirement for any computer system that supports concurrent engineering meetings is that it integrates efficiently with the other computer systems that support the concurrent engineering team (e.g., Computer-Aided Design, engineering data management).

Most of the research in computer support for meetings is technology driven. The need for the computer is assumed. When the use of the computer is a given, the problem becomes one of figuring out how best to apply this technology. The fact that the authors uncovered only one piece of literature that discussed when not to use computers supports this finding (Gerstein, 1990). Computer support for meetings must consider the behavioral as well as the technical aspects of group problem solving. The goal should be to enhance positive aspects of group work while eliminating the negative features. Computers should be employed to do things computers do well--record, store, and calculate enabling people to explore the more creative aspects of problem solving.

The computer-supported-meeting research community has the same needs as those identified by McGrath and Altman in their critique of the small group research field (McGrath and Altman, 1966). These needs include--

- Theory and integrating concepts.
- Intellectual controversy and subjectivity as a research stimulant.
- Research methods that go beyond the laboratory.
- Standardization in concepts, terms, and operations.

McGrath and Altman claim that many of the problems associated with the field come from the traditions and norms of the university community and from the methods used to fund research. University researchers are funded and promoted for doing unique work, so they tend to develop individual theories, methods, and terms.

B. AREAS FOR ADDITIONAL RESEARCH

During the course of this study, the authors identified many areas that could benefit from additional research. Among these are documentation of the concurrent engineering decision process, documentation of the lessons learned about the concurrent engineering process, and evaluation and training of the concurrent engineering team members.

1. Documentation of the Decision Process

In IDA's first research report published for the Unified Life Cycle Engineering (ULCE) program, Brei *et al.* identified one of the desired architectural features of an ULCE system: "documentation of design decisions and their rationales must be generated and made available to all persons who will be affected by these decisions" (Brei *et al.*, 1988). The recording of the design decision rationale has been a recurring theme in IDA's research recommendations for the ULCE program, and it continues to be an important element for the concurrent engineering program.

Documentation of the concurrent engineering team's efforts is especially important because of the iterative nature of the definition process. "The product and process definition teams must pursue multiple design approaches, and thus keep track of different versions of particular design solutions for each design approach" (*Engineer's Design Notebook*, 1990). In addition, new products are often redesigns of previous products. The trail of design decisions reached for a product as well as qualitative empirical information, such as the rules of thumb used and the rationale behind the decisions, is valuable information for any future product and process definition team. Documentation of

the rationale should include any quantitative information used to reach it, such as a trade study analyses. The amount of detail contained in this audit trail is open to debate, but general agreement exists on the fact that more information than just the design data and the final drawings must be kept in a manageable form. Other team records, such as meeting agendas and minutes and presentation materials, should also be kept for complete process documentation.

Although most of the companies visited for this study recognized the need for capturing the design decision rationale, and applications are being developed in industry and academia, this research field is still in its infancy. Questions still need to be answered and additional research needs to be done on this topic. What information is important to record and how should the information be captured? What forms of access are required or allowed for this information? How should the information be represented for easy utilization?

A reported benefit of computer support for meetings is the ability to document decision rationales, but is the documentation produced by current approaches adequate for product and process definition projects? For example, the *Design Journal* from Microelectronics and Computer Technology Corporation (MCC) supports group design deliberation as well as single-user design annotation. "It allows designers to attach (hypertextually) design rationale (design decision-making information) to arbitrary design artifacts that may be geographically distributed" (*MCC Technology Catalog*, 1990). Can this technology be used effectively by concurrent engineering teams?

Researchers of the design process have recognized that what designers say they do and what they actually do can be very different (Brei, Dierolf, and Richter, 1989). Research into methodologies for capturing and representing the decision rationale of the product and process definition should be multidisciplinary (domain independent) and conducted in conjunction with those researchers who study the design process and the information generated and required during that process.

2. Lessons Learned about the Concurrent Engineering Process

The importance of lessons learned is illustrated by the fact that a primary duty of concurrent engineering team coaches at McDonnell Douglas Missile Systems Company (MDMSC) is to capture the lessons learned by the team. MDMSC's goal is to make the concurrent engineering team self-sufficient so that the coaches can leave the team, but the

coaches can leave the team only when another mechanism is in place to capture the lessons learned.

Another lesson learned at MDMSC is that tracking the problems is just as important as tracking the successes of a concurrent engineering team, and they plan to record both the successes and the problems. The Northrop Aircraft Division (NAD) System Integration Engineering (SIE) working group also found that discussing the problems the team might encounter in accomplishing their mission (gleaned from the lessons learned) was beneficial to the team at the first or second meeting. Contrary to what one might believe, NAD found that bringing potential problems out into the open is not an inhibitor to the team process.

The lessons learned by an organization in implementing concurrent engineering can be invaluable to another company, just as the lessons learned from field data on a particular product are useful. The lessons learned doing concurrent engineering should provide information about the process of doing concurrent engineering--what works and what doesn't work. These lessons learned need to be documented in such a way that they can be retrieved and analyzed quickly and easily. General Dynamics Land Systems (GDLS) has amassed a substantial collection of lessons learned during its M1A2 project, and it would be useful to have this information in a convenient form. Documentation of the lessons learned, however, requires answers to most of the questions posed for recording of the decision rationale. Research is needed to develop a methodology for recording and retrieving lessons learned on concurrent engineering. This methodology should be useable by any organization, but an organization that already has a considerable collection of lessons learned would be best chosen as the test case.

3. Performance Evaluation of Concurrent Engineering Team Members

Questions about how to most effectively evaluate team members and reward team success were prevalent among the companies visited for this study. The recommendation in most of the team building literature is that the team should be evaluated and rewarded as a team, not just as individual members. Although most companies realize this, it remains a tough problem because of the many organizational and political issues encountered in trying to implement such a scheme. The GDLS M1A2 concurrent engineering team has compiled a list of excuses that people have used to avoid taking concurrent engineering seriously or implementing the process with full participation of all the disciplines. The first excuse on the list is that methods of evaluating performance are still being established. Evaluation measures for success of the team and for the performance of the individuals on the team must be developed and implemented. The ATF TQM team at NAD has spent 4 years in

rigorous debate over what team building and team maintenance is all about. Guiding principles have now been prepared for many of the issues involved with bringing together a cross-functional team including the reward structure and revised career paths. Research is needed, based on industry experiences such as at NAD, into the kinds of performance evaluations, incentives, and promotion considerations that best support the functioning of the concurrent engineering teams.

4. Training Requirements for Concurrent Engineering Team Members

Training required for concurrent engineering goes beyond traditional engineering analysis education. In fact, until engineering education adopts practices that contribute to a concurrent engineering environment, training is needed to overcome the single-disciplinary, individualist thinking. Employees need to be trained in group dynamics and how to work as team members. Research needs to be done to define the training requirements for concurrent engineering. This research should be done in conjunction with research into performance measures for concurrent engineering teams, since training that does not contribute to an employee's performance measures will not be valued (Holpp, 1989).

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